

Policy evaluation of vehicle exhaust standards in Japan from 1995 to 2005 based on two human health risk indices for air pollution and global warming

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Abstract Measures for vehicle exhaust emissions aimed at reducing either air pollution or global warming could have counterproductive effects on one another. Increasing diesel passenger vehicles, which generally have lower CO₂ emissions than gasoline counterparts, leads to increasing particulate matter (PM) emissions, while gasoline has lower PM emissions than diesel. It is said that stringent limits on PM emission factors discourages improved CO₂ emission factors. Without including both effects in a risk evaluation, one cannot evaluate whether the total risk is reduced or not. Hence, we evaluated representative exhaust emission measures based on risk evaluation for both air pollution and global warming. Considering consumer choice between diesel and gasoline passenger vehicles and emissions standards adopted in Japan from 1995 to 2005, we built five cases for vehicle policy evaluation. For each case, we estimated disability-adjusted life years (DALY) as an index of human health risk caused by lung cancer linked to inhalation exposure of elemental carbon in PM as well as due to global warming linked to CO₂. The results of our

risk evaluation reveal that the case adopting the 2005 new long-term Japanese emission standard reduces the human health risk caused by lung cancer due to air pollution by 0.6×10^3 DALY, but would increase the risk due to global warming by 31.9×10^3 DALY compared with the case of adopting EURO 4, for the same conditions of passenger vehicle choice from 1995. These results suggest that the characteristics of Japanese emissions standards are mainly designed to reduce air pollution.

Keywords Risk evaluation · Policy evaluation · DALY · Vehicle exhaust emissions · PM · CO₂

1 Introduction

The importance of decision-making based on quantitative risk evaluation has been extensively reviewed (Linkov et al. 2014), with many discussions arguing for institutionalization of this process. Although vehicle exhaust emissions have been considered to be a significant risk source due to air pollution and global warming, risk-based decision-making has not yet been used for management of risks associated with vehicle exhaust emissions. We believe that the trade-off between reducing air pollution and greenhouse-gas (GHG) emissions becomes difficult in quantitative risk evaluation. In fact, the Central Environment Council (CEC) of Japan (1997) reported qualitatively that exhaust emissions and fuel economy (closely related to CO₂ emissions), in particular, exhibited a marked trade-off relationship, making it extremely difficult to significantly reduce exhaust emissions while improving fuel efficiency at the same time.

In Japan, air pollution from vehicle exhaust has been improved by introducing command and control strategies

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such as specification of vehicle emissions standards and environmental standards. In particular, the Japanese government has discussed this since 1997 (CEC 1997), and by 2002 introduced the 2005 new long-term standards (CEC 2002). In contrast to Japan, the EU introduced the EURO 4 standard in 1998 (EU 1998). The Japanese standard required lower NO_x and particulate matter (PM) emissions from passenger vehicles compared with the EU standard. Considering the trade-off mentioned above, these countermeasures could have counterproductive effects on one another in terms of environmental risk.

In a risk analysis considering such trade-offs, Tengs et al. (1995) evaluated and compared 500 interventions based on quantitative results for cost-effectiveness in terms of life-years saved as estimated by two trained reviewers who reviewed documents for each intervention based on three criteria. This study indicated that use of a common analytical framework and evaluation index for reevaluating risks enables incorporation of various quantitative measures. As vehicles emit not only air pollutants but also greenhouse gases, the impact of countermeasures on emissions needs to be evaluated using a common index for these different kinds of emissions. To address this issue, disability-adjusted life years (DALY) (Murray and Lopez 1996) have been employed to evaluate the comparative risk context. DALY consists of years of life lost (YLL) as well as years lost due to disability (YLD).

To predict future strategy directions toward implementing risk-based decision-making for exhaust emissions management, we focused on determining characteristics of past decisions based on risk evaluations, but considering risks as trade-offs. Therefore, our research objectives are: (1) to evaluate past measures for vehicle exhaust emissions in terms of major human health risks caused by air pollution and global warming, and (2) to evaluate the characteristics of past Japanese measures based on a human health risk evaluation, comparing both actual and virtual measures. In our study, we used two main variables: the choice of passenger vehicle between diesel passenger vehicle (D-PV) and gasoline passenger vehicle (G-PV), and the vehicle exhaust emissions standards in Japan from 1995 to 2005. To assess human health risk, we built cases for risk comparison using a combination of these two variables.

2 Framework

To evaluate past measures, we built cases that reflect actual past measures as well as hypothetical ones for comparison. To evaluate human health risks, we employed a unified index and compared risks at different time points. Our main analytical boundary conditions are described below.

2.1 Target area

To evaluate the effectiveness of Japanese regulatory decisions, the target area was Japan.

2.2 Time period

The chosen time period was 2005.

2.3 Target risk

We focused on PM, as one of the most concerning air pollution indicators, and CO₂, as a representative GHG causing global warming. In our risk evaluation for PM, we focused on lung cancer caused by inhalation exposure to elemental carbon (EC) in diesel exhaust particles (DEP) based on data from the California Environmental Protection Agency, USA (California EPA 1998). We regarded DEP as PM from D-PV, but not from G-PV. In our risk evaluation for CO₂, we focused on five human disease indicators (malaria, diarrhea, malnutrition, drowning, and cardiovascular disease) reflecting global warming related to CO₂, after Schryver et al. (2009).

2.4 Risk evaluation

We employed a typical procedure for evaluating human health risk caused by lung cancer linked to EC or caused by global warming linked to CO₂. For EC-related risks, we estimated the DALY and the excess lifetime lung cancer risk at the 95th percentile for the Japanese population. For CO₂-related risks, we estimated the DALY impact caused by global warming. The DALY index was employed for comparison of human health risks at different endpoints, or for determination of the total human health risk for all cases. The other index used for comparison was an estimated lifetime risk of less than 10⁻⁵, corresponding to what is known as the virtually safe dose (Gaylor 1989). These two indices were used to compare risks in the trade-off and to determine the characteristics of measures in each case.

2.5 Case settings

We focused on actual measures used from 1995 to 2005 in Japan. We selected this period because 1995 was the year when the holding D-PV composition ratio began to decrease in Japan, whereas in Europe, increasing D-PV ratios occurred from the 1990s (Cames and Helmers 2013). This change from D-PV to G-PV was a specific one, and we expected this change to affect variables associated with human health risk. In addition, PV are used for 10 years on

average in Japan (AIRIA 2015), so there is about a 10-year delay in implementing decisions pertaining to vehicle exhaust emissions measures. For these reasons, we focused on the period of 1995–2005 and the choice of PV type.

3 Materials and methods

Figure 1 shows the procedure used for risk evaluation in our study.

3.1 Case settings

Table 1 presents the five cases defined in this study; it outlines the variables used and gives values for the two main drivers for risk. One driver is the choice of PV type, with changing holding PV composition ratio through time, and the other driver is vehicle emissions standards, with

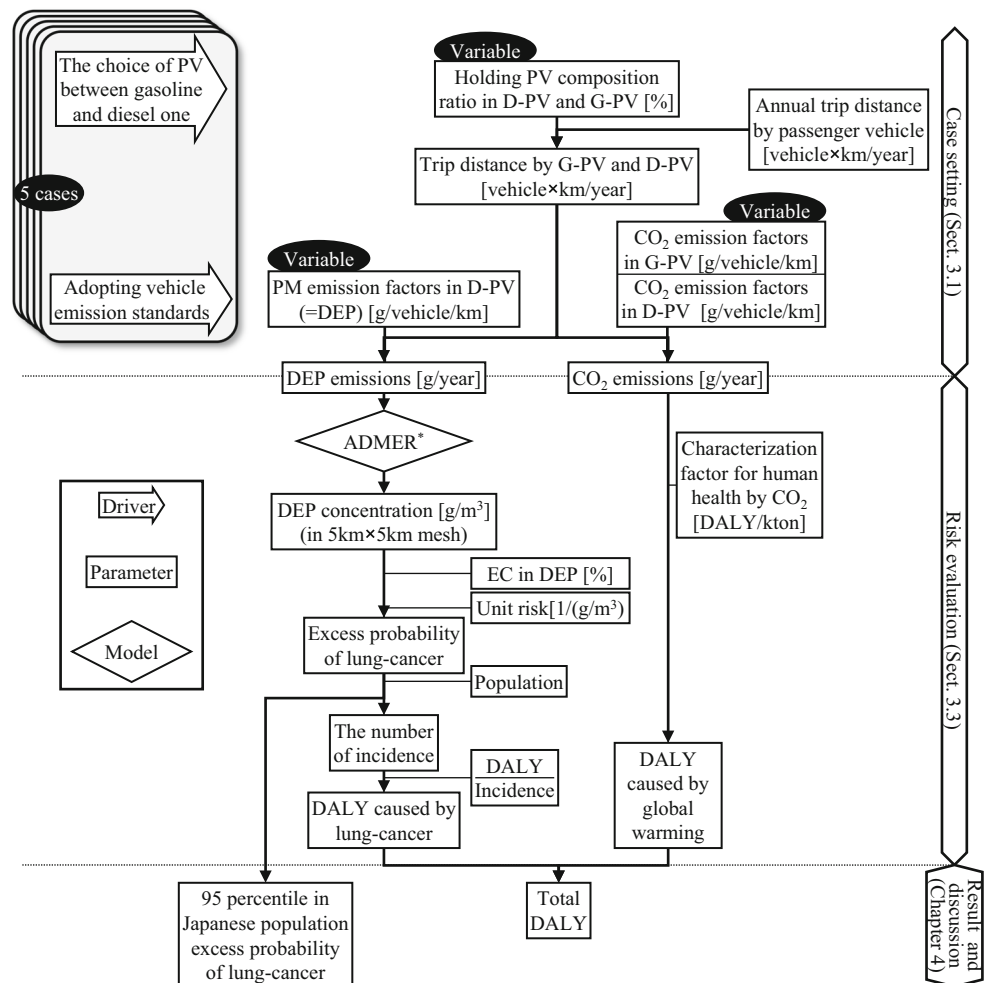
changing emission factors through time. The values of these two drivers differentiate these five cases, resulting in changes in other variables, as well as both DEP and CO₂ emissions.

3.1.1 Choice of passenger-vehicle type by consumers

We set one of two possible choices of PV type in each case. In one set of cases, we let the choice of G-PV by consumers increase from 1995 to 2005, as occurred in Japan. In the other cases, we left the choice of PV type unchanged from 1995 to 2005.

Thus, in cases 1, 4, and 5, the holding PV composition ratio between D-PV and G-PV was assumed to be 11:89 % (i.e., the same as in 1995 in Japan), while in cases 2 and 3, we assumed that G-PV were chosen more than in 1995, with a holding PV composition ratio between D-PV and G-PV of 4:96 % (i.e., the same as in 2005 in Japan).

Fig. 1 Entire procedure of risk evaluation



*ADMER: Atmospheric Dispersion Model for Exposure and Risk Assessment provided by AIST(National Institute of Advanced Industrial Science and Technology)

Table 1 Case settings for PV choice and exhaust emissions standards employed in this study

Case	Outline	Driver	
		PV preference	Emissions standards
1	PV choice between D-PV and G-PV was assumed to be unchanged from 1995, with holding PV composition (D-PV:G-PV) of 11:89 % 1994 short-term standards were assumed, while emission factors were assumed to remain at the actual ones for 1995 in Japan We prepared this case as a baseline to compare effects of various measures, so we set the holding PV composition and the emission factors as in 1995	Unchanged from 1995 ^d	1994 short-term ^a
2	G-PV was assumed to be chosen more than 1995, with PV composition (D-PV:G-PV) of 4:96 % 2005 new long-term standards were assumed throughout, while emission factors were those for 2005 in Japan These measures reflect those for 2005 in Japan	Greater choice of G-PV compared with 1995 ^d	2005 new long-term ^b
3	G-PV was assumed to be chosen more than 1995, with PV composition (D-PV:G-PV) of 4:96 % The EURO 4 standard was adopted, and emission factors were assumed to be the virtual ones calculated by PV for 2005 in Europe (METI 2005). These measures are virtual ones for 2005 in Japan	Greater choice of G-PV compared with 1995 ^d	EURO 4 ^c
4	The choice of PV between D-PV and G-PV was assumed to be unchanged from 1995, with PV composition (D-PV:G-PV) of 11:89 % 2005 new long-term standards were assumed throughout, while emission factors were those for 2005 in Japan	Unchanged from 1995 ^d	2005 new long-term ^b
5	The choice of PV between D-PV and G-PV was assumed to be unchanged from 1995, with PV composition (D-PV:G-PV) of 11:89 % The EURO 4 standard was adopted, and emission factors were assumed to be the virtual ones calculated by PV for 2005 in Europe (METI 2005). These measures are virtual ones for 2005 in Japan	Unchanged from 1995 ^d	EURO 4 ^c

G-PV gasoline passenger vehicle, *D-PV* diesel passenger vehicle

^a MLIT (2005a, b)

^b CEC (2002)

^c EU (1998)

^d METI (2005)

3.1.2 Emission factors reflecting vehicle exhaust emissions standards

The relationships between the employed drivers and the values used for emissions of the related variables are based on actual measures and observed values.

Here, we focus on the maximum value of PM emissions according to the vehicle emissions standards as well as on-road emission factors in the EU and Japan. The maximum value of PM emissions for D-PV in the EURO 4 standard is 0.025 g/km (EU 1998), while the value in the Japanese new long-term standard since 2005 has been 0.013 g/km (CEC 2002). Thus, the Japanese standard is more stringent. Based on a survey of actual emissions by vehicles in each market, the PM emission

factor in England (in the EU) was 0.013 g/km (METI 2005), while in Japan it was 0.008 g/km at 30 km/h (Dohi et al. 2012). We compare emission factors at 30 km/h because the emission factor for G-PV in METI (2005), which was used as the reference for D-PV, was similar to the emission factors at 30 km/h measured for G-PV in Dohi et al. (2012). In contrast, the on-road CO₂ emission factor in Japan was 166 g/km, while in England it was 133 g/km.

These relationships between emissions standards and actual emission factors show that adopting the lower maximum value for PM emissions is linked to a lower PM emission factor but higher emission factor for CO₂. So, adopting these different vehicle emissions standards led to changes in emission factors, including for CO₂, allowing us

to explore their effects in the different cases, hence our selection of exhaust emissions as one of the main drivers.

Table 1 shows that we used either the 2005 new long-term standard (CEC 2002) or the EURO 4 standard (EU 1998) in our cases (except for case 1). In case 1, we assumed emissions standards based on the 1994 short-term standards, and emission factors were derived from actual ones in 1994 in Japan (Dohi et al. 2012; Namikawa et al. 2003). In cases 2 and 4, we set the 2005 new long-term standard for Japan, and the emission factors for D-PV and G-PV were assumed to be the same as the actual emission factors in 2005 in Japan (Dohi et al. 2012; Namikawa et al. 2003). In contrast, in cases 3 and 5, we used the EURO 4 standard, and the emission factors for D-PV were assumed to be the same as the virtual emission factors calculated from actual vehicle tests in England (METI 2005).

The emission factors for G-PV in the EURO 4 standard were assumed to be the same as the actual emission factors in 2005 in Japan, because the suspended particulate matter (SPM) limit was the same for the EURO 4 standard and the Japanese 2005 new long-term standard.

3.2 Estimation of DEP and CO₂ emissions

DEP emissions are only included as PM emission from D-PV exhausts, and not for G-PV exhausts. Both PV types emit CO₂. We assumed that the annual trip distance in a D-PV and G-PV were the same. Thus, the ratio between the annual trip distance in D-PV and G-PV was assumed to be the same as the holding PV composition ratio in each case. To estimate real exhaust outputs, we used emission factors and trip distances based on velocity for each Japanese prefecture.

The emission amount $E_{m,n,o}$ (g/year) for case m , substance n , and prefecture o was calculated using Eq. (1):

$$E_{m,n,o} = \sum_p \sum_q (\text{HPVC}_{m,p} \times \text{TD}_{o,q} \times \text{EF}_{m,n,p,q}), \quad (1)$$

where m indicates the case (1, 2, 3, 4, 5), n the substance (DEP, CO₂), o the prefecture in Japan (Japan has 47 prefectures), p the vehicle type (D-PV, G-PV), q the velocity class defined in 5 km/h intervals, $E_{m,n,o}$ the annual emission amount (g/year) for case m , substance n , and prefecture o , $\text{HPVC}_{m,p}$ the holding passenger vehicle composition ratio (%) for case m and vehicle type p , $\text{TD}_{o,q}$ the annual trip distance (vehicle \times km/year) for prefecture o and velocity class q , and $\text{EF}_{m,n,p,q}$ the emission factor (g/km) for case m , substance n , vehicle type p , and velocity class q .

The derivation of $\text{TD}_{o,q}$ (vehicle \times km/year) is presented in Appendix 1 of the Electronic Supplementary Material (ESM) (MLIT 2005a, b), while $\text{EF}_{m,n,p,q}$ (g/km) is shown in Appendix 2 of the ESM (Dohi et al. 2012; Namikawa et al. 2003; METI 2005).

3.3 Human health risks caused by lung cancer and global warming

3.3.1 Lung cancer caused by inhalation exposure to EC in DEP

To estimate DEP spatial concentrations (g/m³), we employed the software Atmospheric Dispersion Model for Exposure and Risk Assessment (ADMER version 2.6, Higashino et al. 2003). ADMER is based on a plume-puff model using general air pollutant dispersion theory. An outline of ADMER is given in Appendix 3 of the ESM. The parameters required in ADMER are described in Appendix 4 of the ESM.

To evaluate the risk caused by exposure to DEP, we followed the method used by the California EPA (1998). We focused on lung cancer caused by inhalation exposure to EC in DEP. The concentration of EC, given by $D_{m,EC}$, for various cases and mesh sizes (r), was calculated using Eq. (2):

$$D_{m,EC,r} = 0.697 \times D_{m,DEP,r}, \quad (2)$$

where r is the mesh size (for a mesh defined as a 5×5 km² grid for Japan in this study), with values obtained from ADMER, $D_{m,EC,r}$ is the EC concentration (g/m³) for case m and the r -th mesh, and $D_{m,DEP,r}$ is the DEP concentration (g/m³) for case m and the r -th mesh estimated by ADMER. Note that the factor 0.697 is the ratio of EC in DEP for small cars (PV in this study) (Yamamoto et al. 2008).

The excess lifetime lung cancer risk, $\text{ER}_{m,r,s}$ for case m , the r -th mesh, and cancer type s (lung cancer), was calculated using Eq. 3. The DALY impact caused by inhalation of EC, $\text{DALY}_{m,EC}$ for case m was calculated using Eq. 4. In this study, we employed the geometric mean of the unit risk: $\text{UR}_{EC,s} = 6 \times 10^{-4} [1/(\text{lifetime-}\mu\text{g/m}^3)]$ for lung cancer caused by EC, derived from the California EPA (1998). The (DALY/incidence) _{t} value for lung cancer was 12.587 DALY/incidence, as shown in Itsubo and Inaba (2010).

$$\text{ER}_{m,r,s} = D_{m,EC,r} \times \text{UR}_{EC,s} \quad (3)$$

where s is the cancer type (lung cancer), $\text{ER}_{m,r,s}$ is the excess lifetime cancer risk for case m , mesh r , and cancer type s , and $\text{UR}_{EC,s}$ is the unit risk [1/(lifetime- $\mu\text{g/m}^3$)] for EC causing cancer type s .

$$\text{DALY}_{m,EC} = \sum_r \left\{ \text{ER}_{m,r,s} \times \text{Population}_r \times \left(\frac{\text{DALY}}{\text{incidence}} \right)_t \right\}, \quad (4)$$

where t is the incidence of lung cancer, Population_r is the population within the mesh (MIAC 2005), $\text{DALY}_{m,EC}$ is the DALY impact of EC for case m , and DALY/incidence is the DALY impact per incidence.

Note that the excess lifetime lung cancer risk at the 95th percentile in the Japanese population means that 95 % of Japanese people were under the excess risk threshold.

The reason for adopting the geometric mean of unit risk according to the California EPA was that the geometric mean provides information on the central tendency of the range; it should not be confused with the best estimate as identified from the available calculations. Furthermore, the DALY impact per incidence in Itsubo and Inaba (2010) was adopted because this value was modified using the available medical statistics in Japan from the original value of DALY per incidence in Murray and Lopez (1996).

3.3.2 Human health risk caused by global warming linked to CO₂ emissions

We estimated the DALY impact as the human health risk caused by global warming linked to CO₂ emissions, after Schryver et al. (2009). Schryver et al. estimated a characterization factor (CF) (DALY/kton) at the endpoint for malaria, diarrhea, malnutrition, drowning, and cardiovascular diseases. We used a CF of 1.76×10^{-2} (DALY/t-CO_{2-eq}), which was calculated with no age weighting and a 0 % discount ratio (egalitarian). In Sect. 3.3.1, the DALY impact for EC exposure was evaluated using the (DALY/incidence)_t value for lung cancer (Itsubo and Inaba 2010) with no age weighting and a 0 % discount ratio as well. We could therefore compare the two DALY values. The DALY impact for CO₂-related health risks, DALY_{m,CO₂}, for each case was calculated using Eq. (5):

$$\text{DALY}_{m,\text{CO}_2} = \text{CF}_{\text{CO}_2} \times \sum_o E_{m,\text{CO}_2,o}, \quad (5)$$

where DALY_{m,CO₂} is the DALY impact for CO₂-related health risks for case *m* and CF_{CO₂} is the characterization factor (DALY/kton) for CO₂ emissions on DALY.

This DALY_{m,CO₂} reflects CO₂ emissions in Japan.

4 Results and discussion

4.1 Estimation of vehicle exhaust emissions for five cases

Table 2 presents the results for each case, giving both parameters and estimated emission amounts. The PM and CO₂ emission factors in Table 2 are for 30 km/h in each case (Dohi et al. 2012; METI 2005; Namikawa et al. 2003). The method used to calculate these emission factors and our calculation results are presented in Appendix 1 of the ESM.

Because case 1 was defined as a reference case for comparing the effects of control measures, we set the

holding PV composition ratio and the emission factors as in 1995, before any measures were implemented. These settings led to higher DEP and CO₂ emission estimates than for the other four cases. DEP emissions were around 44 times higher than for case 2, which had the lowest DEP emissions. CO₂ emissions were around 1.3 times higher than for case 5, which had the lowest CO₂ emissions among our cases. In fact, this case does not represent the risk situation in 1995 in Japan, because factors other than emission factors and holding PV composition ratio were the same as those in 2005 in Japan. However, our research objective was not to reevaluate human health risks in 1995; rather, these settings provide a reference to evaluate the effects of different holding PV composition ratios and emission factors on DEP and CO₂ emissions.

In case 2, we assumed that consumers chose G-PV more than in 1995 and Japan adopted the 2005 new long-term standards. As a result of introducing these measures, the holding PV composition ratio and emission factors were assumed to have the same values as in 2005 in Japan. We therefore regard this case as a reevaluation of the combined measures taken in 2005 in Japan. This combination of holding PV composition ratio and emission factors led to the lowest estimated DEP emissions of 226.6 t/year. CO₂ emissions were estimated as 107.6×10^6 t/year.

In case 3, we assumed G-PV were chosen more often, as in case 2, but adopted the EURO 4 standard. DEP emissions were estimated as 363.9 t/year, and CO₂ emissions were estimated as 105.8×10^6 t/year. DEP emissions in case 3 were higher than in case 2, while CO₂ emissions were lower. We aimed to evaluate the difference in these vehicle emissions standards in terms of emission amount and human health risk.

In case 4, we assumed that the choice of PV type remained unchanged from 1995 and adopted the 2005 new long-term standards. DEP emissions were estimated as 614.1 t/year, and CO₂ emissions were estimated at 109.9×10^6 t/year. This case had the same holding PV composition ratio as case 1, but a different emission factor, so the difference in emissions indicates the reductions achieved by only improving emission factors from 1995 to 2005.

In case 5, we assumed that the choice of PV type remained unchanged from 1995 but adopted the EURO 4 standard. There were differences from case 2 for both drivers. With this unchanged choice of PV type from 1995 and adopting the EURO 4 standard, the emission factors and holding PV composition ratio led to the lowest estimated CO₂ emissions of 105.0×10^6 t/year. However, the estimated DEP emissions of 986.1 t/year were the highest.

Here, we focus on the emission factors in case 2 (and case 4). Generally, D-PV are more fuel efficient, resulting in lower CO₂ emissions for D-PV than for G-PV (EERE

Table 2 Variables and exhaust emissions used for each case

Case	Variables				Estimated annual exhaust emissions amount			
	Emission factors		Holding PV composition ratio (%)					
	PM (mg/km) ^a		CO ₂ (g/km) ^a					
	D-PV	G-PV	D-PV	G-PV	D-PV	G-PV	DEP (t/year)	CO ₂ (10 ⁶ × t/year)
1	126	1.158	250	178	11	89	9947.4	135.3
2	8	0.417	196	145	4	96	226.6	107.6
3	13	0.417	133	145	4	96	363.9	105.8
4	8	0.417	196	145	11	89	614.1	109.9
5	13	0.417	133	145	11	89	986.1	105.0

D-PV diesel passenger vehicle; *G-PV* gasoline passenger vehicle; *DEP* diesel exhaust particle

^a PM and CO₂ emission factors are at 30 km/h, in this instance

2015). However, the emission factors calculated in case 2 show the reverse relationship. The values used in case 2 came from an actual PV survey by Dohi et al. (2012), who reported values where both PM and CO₂ emission factors for D-PV were worse than for G-PV. The lesser improvement in CO₂ emission factors for D-PV is thought to reflect the decrease in D-PV numbers. A decrease in D-PV sales in Japan discouraged installation of updated technologies in D-PV in the market (METI 2005). It is also important to note that we employed emission factors without any modifications.

4.2 Risk evaluation results for five cases

Table 3 presents the results of our risk evaluation: the excess lifetime lung cancer risk at the 95th percentile in the Japanese population, DALY impact from lung cancer

linked to EC inhalation exposure, DALY impact from global warming linked to CO₂ emission, and total DALY impact reflecting both EC- and CO₂-related health risks.

Our results show that the DALY impact of EC emissions was lower by two orders of magnitude than the DALY impact of CO₂ emissions. These results largely depend on the case setting on the choice of PV types and emission factors, endpoints and other inherent factors like the characterization factors (Schryver et al. 2009) in our study. As such, understanding the uncertainty in our results is a very important issue. However, given that the purpose of this study is to compare cases using the same method, we decided that establishing the variance in the risk stemming from CO₂ emissions lay outside the scope of this study.

In case 1, defined as a reference case, the DALY impact of lung cancer, DALY impact of global warming, and total DALY impact values were much larger than for the other

Table 3 Evaluation results of two indices of human health risk

Case	EC ^a		CO ₂		Total DALY (10 ³ × DALY)
	Excess lifetime lung cancer risk at 95 percentile in Japanese population ^a	DALY impact of lung cancer (10 ³ × DALY) ^b	DALY impact of global warming (10 ³ × DALY) ^c		
1	5.83×10^{-4}	75	2382		2457
2	9.96×10^{-5}	12	1894		1905
3	1.03×10^{-4}	13	1862		1874
4	1.04×10^{-4}	13	1934		1947
5	1.23×10^{-4}	15	1848		1863

EC elemental carbon (from diesel exhaust particle exposure), *DALY* disability-adjusted life years

^a Unit risk from California EPA (1998)

^b DALY per incidence (of lung cancer) from Itsubo and Inaba (2010)

^c DALY per CO₂ emission from Schryver et al. (2009)

four cases, because we used emission factors from 1995. In comparison with the other cases, the DALY impact related to EC emissions was 5–6 times larger, while the DALY impact related to CO₂ emissions was approximately 1.2–1.3 times larger. Clearly, vehicle exhaust control measures have reduced the burden on human health.

4.2.1 Risk evaluation results arranged by excess lifetime cancer risk and total DALY impact

Based on the risk evaluation results in Table 3, we plot all the cases in Fig. 2, where the horizontal axis indicates the excess lifetime cancer risk and the vertical axis indicates the total DALY impact. The gray region in Fig. 2 represents values under 10^{-5} or the virtually safe dose (Gaylor 1989) for excess lifetime lung cancer risk.

In Fig. 2, we see that case 2 was evaluated at 9.96×10^{-5} , the lowest value for excess lifetime lung cancer risk at the 95th percentile in the Japanese population. Because case 2 reflects the 2005 new long-term standards, which are relatively stringent in terms of PM, as well as the lower holding D-PV composition ratio (D-PV having higher PM emissions than G-PV) in 2005 in Japan, we can surmise that past Japanese exhaust control measures were designed to reduce air pollution. However, the excess lifetime lung cancer risk at the 95th percentile in the Japanese population in case 2 exceeded 10^{-5} , indicating that we need to reduce PM further to reduce human health risk.

We also focus on the plot for the total DALY impact, for which case 5 was evaluated as having the lowest total DALY impact of 1863×10^3 . Case 5 also had the lowest CO₂ emissions. The reduction in total DALY between

case 1 and 5 was 594×10^3 , representing a decrease of 76 %. For cases 1 and 2, in which the total DALY impact was related to EC emissions, this reduction was 552×10^3 , representing a decrease of up to 78 % compared with case 1. Our risk evaluation results suggest that CO₂ reduction was more effective for decreasing the total DALY impact than EC reduction. Similar results were found for excess lung cancer risk: It was reduced by up to 76 % compared with case 1. However, the DALY values related to both EC and CO₂ emissions were 1863×10^3 DALY. Clearly, to reduce the total DALY impact, we need to consider a combination of air pollution management and global warming management in the future.

Lastly, the difference in total DALY between cases 2 and 5 was evaluated as 42×10^3 . Thus, the difference between cases 1 and 5 was 14.1 times higher than that between cases 2 and 5, suggesting lesser effects between cases 2 and 5.

These results show that the difference in emission factors between 1995 and 2005 reduced the DALY impact to a larger extent than the differences between vehicle emissions standards or the choice of PV type. To further evaluate technological improvements that reduce emission factors, we need additional information with improved time resolution.

4.2.2 Comparison between DALY impact of lung cancer versus global warming

Based on the risk evaluation results in Table 3, we plot four cases in Fig. 3, excluding case 1, to look at the cases adopting the 2005 emissions standards. In Fig. 3, case 2 appears at the origin, while the horizontal axis indicates the DALY difference from case 2 related to global warming and the vertical axis indicates the DALY difference from case 1 related to air pollution impacts on health. Thus, Fig. 3 clearly shows the risk trade-off for each case against

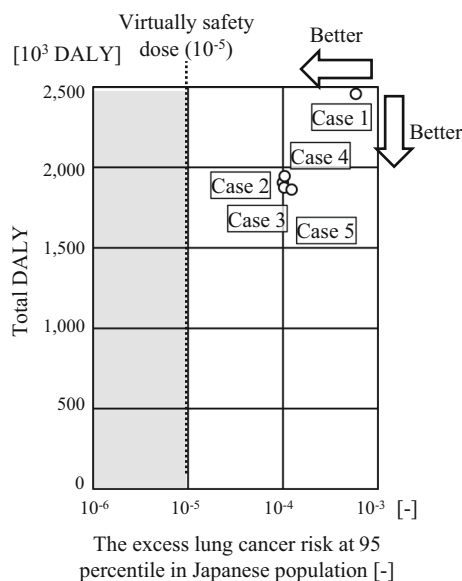


Fig. 2 Result of risk evaluation focusing on the total DALY and the excess lung cancer risk

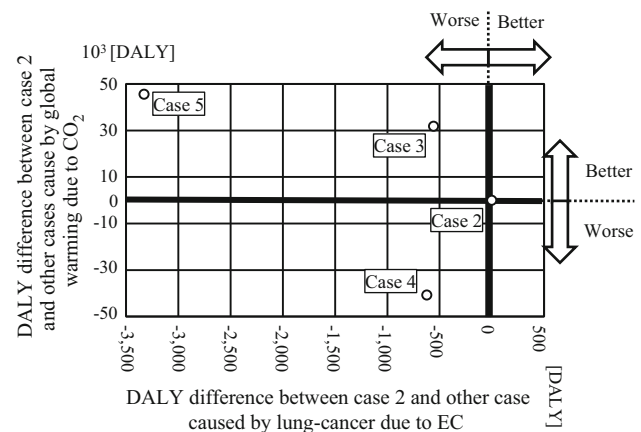


Fig. 3 Case comparison based on DALY by CO₂ and EC

the origin. In addition, Fig. 3 can be used to identify the effects of past measures. Case 3 moves in a direction with worse air pollution but better global warming risk management. Given that the difference between cases 2 and 3 is the adoption of the 2005 new long-term standard versus the EURO 4 standard, emission factors under these different exhaust emissions standards are the driving factor here. Quantitatively, adopting the EURO 4 standard instead of the 2005 new long-term standard led to a reduction of 31.9×10^3 DALY linked to global warming, but an increase of 0.6×10^3 DALY linked to lung cancer.

Likewise, changing the holding PV composition ratio is the difference between cases 3 and 5. Comparing the 1995 holding PV composition ratio of 11:89 % (D-PV:G-PV) with a shift to 4:96 % in 2005 resulted in a 13.8×10^3 DALY reduction in health risk related to global warming, but a 2.8×10^3 DALY increase in lung cancer risk. From another perspective, the differences among the cases indicate how to decrease the targeted risks using a certain driver or variable change. The difference between cases 2 and 4 reflects the choice of PV type, with DALY estimates in case 4 being lower than in case 2, suggesting that decreasing D-PV numbers is one way to decrease the DALY values.

5 Conclusions

We characterized past exhaust control measures based on a human health risk evaluation. We constructed a human health risk evaluation model for lung cancer caused by EC and health damage caused by global warming linked to CO₂. We built both actual and hypothetical cases based on the choice of PV type and vehicle emissions standards determining the holding PV composition ratio and emission factors. From our risk evaluation, we could evaluate exhaust emission policy and evaluate past measures in a quantitative way. We summarize our results in two main conclusions:

1. Introducing exhaust policies from 1995 onwards resulted in reduced human health risks stemming from CO₂ and EC (included in PM) emissions. Case 3, with the same PV composition as in case 2 but using the EURO 4 instead of 2005 new long-term standard, exhibited a reduced DALY impact of global warming by 31.9×10^3 but an increase of 0.6×10^3 DALY for lung cancer. These results show that vehicle emissions standards lead to a risk trade-off. This was also the case for the PV composition. To evaluate risk trade-offs, we illustrate our results on horizontal and vertical axes to compare the relative DALY values based on the two different risks.

2. Settings based on actual measures and the quantitative results showed that past Japanese decisions with regards to exhaust emission control had the intention of preferentially reducing air pollution. Because case 2 exhibited the lowest risk related to air pollution, its excess lifetime lung cancer risk at the 95th percentile in the Japanese population was 9.96×10^{-5} , while the DALY impact for lung cancer was evaluated as 12×10^3 . We set case 2 to have the 2005 long-term standard, which is relatively stringent in terms of PM, as well as a lower D-PV composition, as for 2005 in Japan. Based on case 2, cases 3 and 5 would slightly decrease the human health risk related to global warming, but would increase the human health risk related to air pollution. Case 4 would slightly increase both risks. Thus, we examined and characterized exhaust policies based on case 1.

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References

- AIRIA (Automobile Inspection and Registration Information Association) (2015) Historical data of average use year by vehicle type. https://www.airia.or.jp/publish/statistics/ao11kc00000000z4-att/03_32.pdf. Accessed 18 Oct 2015
- California EPA (Environmental Protection Agency) (1998) For the “proposed identification of diesel exhaust as a toxic air contaminant” part B: health risk assessment for diesel exhaust. <http://www.arb.ca.gov/regact/diesltac/partb.pdf>. Accessed 16 Oct 2015
- Cames M, Helmers E (2013) Critical evaluation of the European diesel car boom - global comparison, environmental effects and various national strategies. *Env Sci Eur* 25:15
- CEC (Central Environment Council, Japan) (1997) Future policy for motor vehicle exhaust emission reduction (second report). <https://www.env.go.jp/council/former/tousin/t07-h0901.pdf>. Accessed 4 Dec 2015
- CEC (Central Environment Council, Japan) (2002) Future policy for motor vehicle exhaust emission reduction (fifth report). <https://www.env.go.jp/en/air/qa/mv/vehicle-fifth.pdf>. Accessed 28 Oct 2015
- Dohi M, Sone S, Takimoto M, Ogawa T, Namikawa Y (2012) Grounds for the calculation of motor vehicle emission factors using environment impact assessment of road project etc. (revision of 2010). In: Technical note of National Institute for Land and Infrastructure Management, Japan, No. 671
- EERE (Office of Energy Efficiency and Renewable Energy, U.S.) About diesels. https://www.fueleconomy.gov/feg/di_diesels.shtml. Accessed 18 Oct 2015

- EU (1998) directive 98/69/EC of the European parliament and of the council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC. http://eur-lex.europa.eu/resource.html?uri=cellar:9ee5d16b-1a4a-4a72-ac90-5e3a0bb1d745.0008.02/DOC_1andformat=PDF. Accessed 16 Oct 2015
- Gaylor DW (1989) Preliminary estimates of the virtually safe dose for tumors obtained from the maximum tolerated dose. *Regul Toxicol Pharmacol* 9:101–108
- Higashino H, Kitabayashi K, Inoue K, Mita K, Yonezawa K (2003) Development of an atmospheric dispersion model for exposure and risk assessment (ADMER). *J Jpn Soc Atmos Environ* 38:100–115
- Itsubo N, Inaba A (2010) LIME2-life-cycle impact assessment method based on endpoint modeling. Maruzen, Japan
- Linkov I, Anklam E, Collier ZA, DiMase D, Renn O (2014) Risk-based standards: integrating top-down and bottom-up approaches. *Environ Syst Decis* 34:134–137
- METI (Ministry of Economy, Trade and Industry, Japan) (2005) Report on the investigative commission for clean-diesel-vehicle prevalence and future vision (in Japanese). <http://www.meti.go.jp/report/downloadfiles/g50418b01j.pdf>. Accessed 16 Oct 2015
- MIAC (Ministry of Internal Affairs and Communications, Japan) (2005) National population census. <http://e-stat.go.jp/SG2/eStatGIS/page/download.html>. Accessed 16 Oct 2015
- MLIT (Ministry of Land, Infrastructure, Transport and Tourism, Japan) (2005a) Annual report of road transport statistics. <http://www.mlit.go.jp/k-toukei/syousaikensaku.html>. Accessed 16 Oct 2015
- MLIT (Ministry of Land, Infrastructure, Transport and Tourism, Japan) (2005b) Road transportation census 2005. Maruzen, Japan
- Murray C, Lopez AD (1996) The global burden of disease. Harvard University Press, Cambridge
- Namikawa Y, Takai Y, Ohsihiro N (2003) Calculation base of motor vehicle emission factors, Technical note of National Institute for Land and Infrastructure Management, Japan, No. 141
- Schryver A, Brakkee KW, Goedkoop MJ, Huijbregts M (2009) Characterization factors for global warming in life cycle assessment based on damages to humans and ecosystems. *Environ Sci Technol* 43:1689–1696
- Tengs TO, Adams ME, Pliskin JS, Safran DG, Siegel JE, Weinstein MC, Graham JD (1995) Five-hundred life-saving interventions and their cost-effectiveness. *Risk Anal* 15:369–390
- Yamamoto K, Kuwana J, Mizusawa Y, Tohno S (2008) Estimation of elemental carbon emission and spatial distribution of atmospheric concentration in Kansai area. *J Jpn Soc Atmos Environ* 43:245–256